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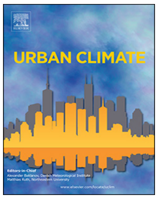

# The impact of semi-open settings on ventilation in idealized building arrays

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ABSTRACT

Semi-open settings (or hanged walls) above the pedestrian level in street canyons can provide protection to pedestrians from heavy-rain and strong sunshine, but may also influence street ventilation and thus pollutant dispersion. By performing computational fluid dynamics (CFD) simulations and employing ventilation concepts of net escape velocity (i.e. diluting rate for exhale effect) and the age of air (i.e. freshness of air for inhale effect), this paper investigates the effects of low-level semi-open settings on ventilation in idealized block arrays with rectangular or square form (building height/street width $H/W = 1.25$) under neutral atmospheric conditions. Four upstream wind directions of 0° (parallel), 15°, 30°, 45° between the approaching wind and the main street axis and four widths of semi-open settings (Ws = 0 m, 2 m, 4 m, 6 m) are investigated. Results indicate that the increasing width of semi-open settings produce greater age of air (i.e. older air) and smaller net escape velocity (i.e. less diluting rate) than those without semi-open settings. The wider semi-open settings experience the worst ventilation. In addition, the approaching wind directions of 0° and 15° lead to worse ventilation than 30° and 45°, for both rectangular and square forms.

## 1. Introduction

The urban canopy layer (UCL), where people live and ground-level vehicle emission sources are, is defined as the layer of the atmosphere from the ground to the rooftop of buildings in urban areas (Fig. 1a). Improving UCL ventilation or city breathability (Ng, 2009; Yang et al., 2013; Zhang and Gu, 2013; Kim, 2015) by flow over and through the UCL can help pollutant dilution and decreasing the related building energy consumption (Du et al., 2017) City breathability was defined as a UCL ventilation concept representing the potential of UCL space to dilute and remove pollutants, heat, moisture and other scalars. The starting point of city breathability is the assumption that the surrounding air is relatively clean, and wind can deliver cleaner external air into UCL (inhale effect) and removing pollutants out (exhale effect). Horizontal advection and vertical turbulent diffusions have been found to have the major contribution on city breathability. The capacity of city breathability is determined by the interaction between the approaching wind and urban morphology. Recently, their correlation have been assessed by some ventilation indices such as velocity ratio (Ng, 2009), age of air and air change rate per hour (Li et al., 2005; Hang et al., 2009; Hang et al., 2013; Buccolieri et al., 2010; Hang and Li, 2011; Luo and Li, 2011; Lin et al., 2014; Ramponi et al., 2015; Nazarian and Kleissl, 2016), purging flow rate and net

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**Nomenclature**

| | |
|---|---|
| $A$ | area of a surface |
| $B$,$H$, $L$,$W$ | building width, building height, total length, street width |
| $\bar{c}$ | time-averaged pollutant concentration |
| $K_c$,$v_t$ | turbulent viscosity of pollutant and momentum$K_c = v_t/S_{ct}$ |
| $k$, $\varepsilon$ | turbulent kinetic energy and its dissipation rate |
| $k_0(z)$, $\varepsilon_0(z)$ | turbulence kinetic energy and its dissipate rate at CFD domain inlet |
| $k_s$, $C_s$ | Roughness height, roughness constant |
| $NEV$,$NEV^*$ | net escape velocity and its normalized value |
| $PFR$ | purging flow rate |
| $NEV_{\mathrm{UCL}}$ | net escape velocity for entire UCL volume ($z = 0$ to $z = H$) |
| $NEV_{\mathrm{ped}}$ | net escape velocity at pedestrian level ($z = 0$ to $z = z_p = 2\,\mathrm{m}$) |
| $Q^*$ | normalized flow rate through street openings or street roofs |
| $Q_\infty$ | reference flow rate in upstream free flow to normalize flow rates |
| $S$ | pollutant release rate |
| $S_{ct}$ | turbulent Schmidt number |
| $\tau_p$,$\tau_p{}^*$ | age of air (s) and its normalized value |
| $\tau_0$ | reference time scale |
| $<\tau_p>$ | spatial mean age of air in a space |
| $U_0(z)$ | velocity profiles used at CFD domain inlet for ventilation cases |
| $U_H$ | reference velocity at building height $z = H$ |
| $\bar{u}_i$,$x_j$ | time-averaged velocity components and co-ordinate components |
| $\bar{u}$, $\bar{v}$,$\bar{w}$ | time-averaged stream-wise, span-wise (lateral), vertical velocity |
| $ul$<br>$V$ | velocity vector |
| $Vol$ | control volume |
| $x$, $y$, $z$ | stream-wise, span-wise, vertical directions |
| $z_0$ | surface roughness |

escape velocity (Bady et al., 2008; Hang et al., 2012, 2015), exchange velocity and in-canopy velocity (Hamlyn and Britter, 2005; Panagiotou et al., 2013; Chen et al., 2017), pollutant exchange velocity (Liu et al., 2005; Kubilay et al., 2017) etc. In particular, the local mean age of air (Hang et al., 2009, 2013; Buccolieri et al., 2010; Hang and Li, 2011; Luo and Li, 2011; Ramponi et al., 2015) represents how long the external air can reach a place after it enters the UCL; it has been widely adopted to quantify the 'inhale

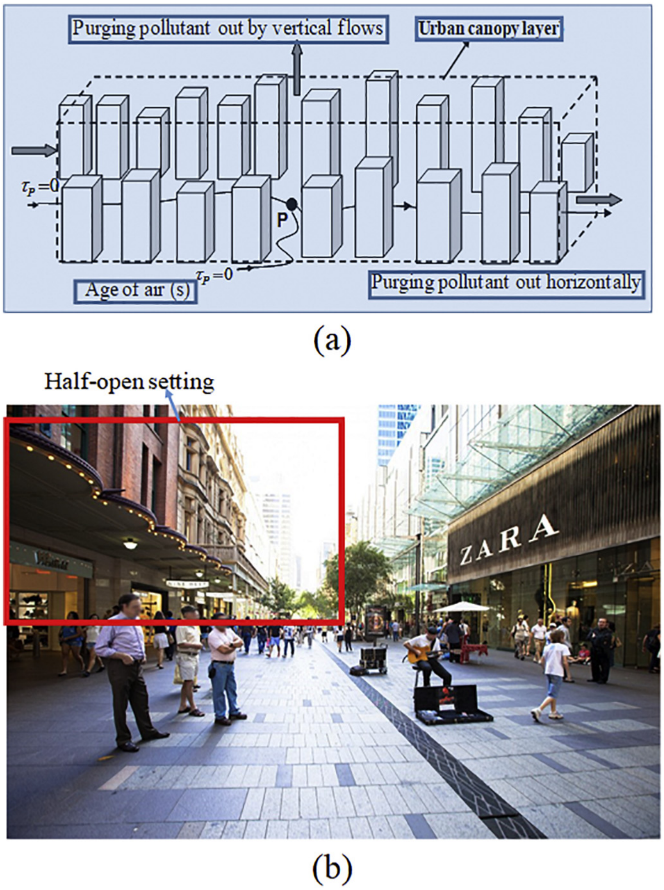

**Fig. 1.** (a) Definition of city breathability in the urban canopy layer (UCL). (b) Example of building with half-open setting above pedestrian levels.